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Breeding ecology of a translocated population of great spotted kiwi (*Apteryx haastii*)

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Abstract: Breeding success, survival, and lack of dispersal are all fundamental to the long-term success of animal translocations. Monitoring breeding of great spotted kiwi (roroa, *Apteryx haastii*) is challenging because they have a low reproductive rate and may abandon eggs or chicks if disturbed. Roroa were translocated to the Flora Stream area, Kahurangi National Park, New Zealand, by the community group, Friends of Flora Inc. and the Department of Conservation. We monitored 55 post-translocation breeding attempts, among 14 roroa pairs, over eight years. Mustelid predation was the only identified cause of chick death. Chick survival to one year is estimated as 26–52%. This is sufficient for population growth, but all chicks known to have survived were hatched by only two pairs. A strategy to monitor long-term genetic health is proposed.

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Key words: great spotted kiwi, roroa, *Apteryx haastii*, translocation, breeding, predator control, camera monitoring, mustelid, wēkā

INTRODUCTION

The great spotted kiwi (roroa, *Apteryx haastii*) is classified as globally threatened, Vulnerable by the IUCN (BirdLife International 2020). It is classified as Nationally Vulnerable in New Zealand based on a moderate to large population (5,000–20,000) and predicted decline of 30–70% over three generations, with qualifiers of 'data poor' and 'recruitment failure' (Townsend *et al*. 2008; Robertson *et al*. 2017). Predation by introduced stoats (*Mustela erminea*) is the primary reason for kiwi recruitment failure, but can be managed by trapping and use of vertebrate poisons (Germano *et al*. 2018). Cats (*Felis catus*) are also a threat to kiwi chicks (Alley & Buckle 2015).

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The long-term goal of recent Kiwi Recovery Plans is to restore and, wherever possible, enhance the current abundance, distribution and genetic diversity of all kiwi taxa (Holzapfel *et al*. 2008; Germano *et al*. 2018). Translocation to areas with predator control has been used extensively as a tool to achieve this goal (Miskelly & Powlesland 2013). In 2010, 2013, and 2016, the community group Friends of Flora Inc. (FOF) and the New Zealand Department of Conservation (DOC) translocated roroa to the Flora Stream area (henceforth referred to as 'the Flora') to the north of Tu Ao Wharepapa (Mt Arthur) in Kahurangi National Park (172°41'E, 41°10'S; Fig. 1). The Flora was considered suitable for roroa reintroduction because it was recently occupied by roroa and is connected to the rest of the NW Nelson population via the adjacent Cobb

Valley (Toy *et al. unpubl. data*). The threats presumed to have led to the disappearance of roroa have been addressed; it has more intensive mustelid control than in much of the distribution range of roroa, and a permit is required to take dogs, a threat to adult roroa, into National Parks in New Zealand. In addition, access is comparatively easy, a necessity for post-translocation monitoring by a community group, and beneficial for public engagement. FOF's vision is to restore and enhance the biodiversity values of the Flora. The translocations advanced these aims by reintroducing a lost taonga (treasure). In addition, the predator control that enables kiwi population growth will also benefit many other native species (Germano *et al.* 2018).

Four separate translocations were undertaken: 12 roroa were sourced from Clark River (40°56'S, 172°32'E) in 2010; 12 from New Creek (41°48'S, 171°55'E), and eight from Upper Roaring Lion River (41°03'S, 172°26'E) in 2013; and 12 from South Gouland (40°56'S, 172°20'E) in 2016 (Fig. 1). Each translocation, including its follow-up monitoring, was approved by the Kiwi Recovery Group and DOC, and was undertaken in accordance with best practice at that time (Robertson & Colbourne 2003). Operational targets relating to successful transfer and establishment were met (Toy & Toy 2020).

The translocations' longer-term conservation goals included: establishing a self-sustaining population in which roroa successfully breed and young birds form new pairs within the protected area within 10 years; and roroa become common in the Flora area, with juvenile kiwi moving into adjacent areas within 50 years.

Demonstrating if these goals were met was complicated by roroa biology; they are nocturnal, notoriously susceptible to disturbance, and have naturally low productivity (McLennan & McCann 1991). Merely walking past a nest has caused incubation failure (Eason 1988; McLennan & McCann 1991). A single egg is laid, although females may lay again if nest failure occurs. Males generally incubate during the day with females sharing night-time incubation, although there are periods when neither adult is on the nest (McLennan & McCann 1991). Chicks are precocial, but use the nest burrow for daytime roosting for at least one month after hatching (Forder 2014). Family bonds are long-lasting with some young birds being found with their parents for up to 4.5 years (Jahn *et al*. 2013). Recruitment is low; the age of first breeding in wild-hatched roroa ranges from 3 years 10 months to eight years (G. Kates *pers. comm*.; J. Haley *pers. comm*.).

Understanding the breeding success of a species is crucial for its conservation but this can be time consuming and challenging (Taylor *et al*. 2014). We monitored breeding of roroa for eight years after the first translocation until population growth had been demonstrated. However, a self-sustaining population requires not only that recruitment exceeds mortality, but that the effective population size (the number of individuals contributing genetically to the population) is sufficient to avoid inbreeding and ensure there is enough genetic variation to enable survival and adaptation in the face of environmental change (IUCN/SSC 2013; Taylor *et al*. 2017). For long-lived species with relatively low reproduction rates, monitoring post-translocation breeding success for long enough to determine genetic sustainability requires long-term funding and commitment (Parker *et al.* 2013).

Translocation of a few individuals can result in substantial loss of genetic variation due to founder effects (Keller *et al*. 2012; Ramstad *et al*. 2013). Even if there is good population growth, loss of genetic diversity may occur if there is high variance in reproductive success between founders (Jamieson 2011; Weiser *et al*. 2013), and through inbreeding (Keller *et al*. 2012; Taylor *et al*. 2017). Founder effects may be worse for species: with large body size, which often correlates with larger home range size and thus limits the number that can be protected in a given area; with limited dispersal or mobility, which enhances isolation; and with long generation interval, low reproductive rate, and high parental investment, all of which limit population growth rates (Ramstad *et al*. 2013). Roroa have all these characteristics but they have relatively high genetic diversity compared to other kiwi species (Ramstad *et al.* 2010), and evidence of isolation by distance in roroa has recently been identified (Taylor *et al. in press*.).

The Flora translocation goals did not specifically address genetic diversity. Rather, it was assumed, based on Allendorf *et al.* (2013), that introduction of more than 40 kiwi from a variety of source sites would be sufficient to found a self-sustaining population.

Here we summarise roroa breeding attempts recorded in the Flora to assess the success of the translocations and determine if management of the project area is adequate for recruitment.

METHODS

Site

The project area covers approximately 10,000 ha (Fig. 1) ranging from 700 to 1,500 m altitude. Silver beech (*Lophozonia menziesii*) is the predominant forest canopy species, with red beech (*Fuscospora fusca*) at lower altitudes and mountain beech (*Fuscospora solandri* var. *cliffortioides*) at higher altitudes. Above the tree line there are areas of *Olearia*, *Dracophyllum*, and *Hebe* spp. shrubland and extensive *Chionochloa* spp. grasslands (Toy 2016).

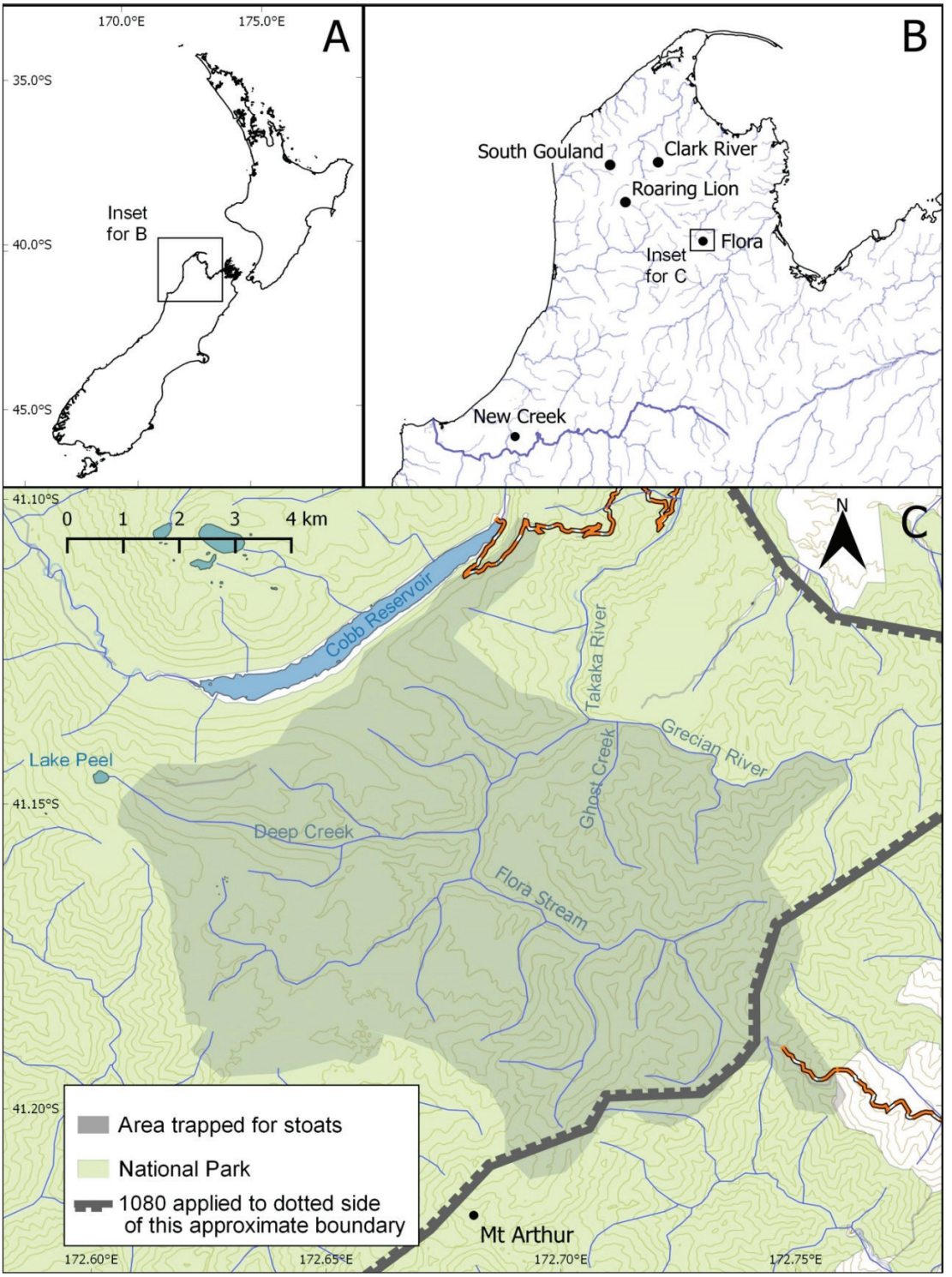

Figure 1. Location of the Flora project area, in New Zealand (A), in relation to the four source sites for translocated roroa (B) and, the extent of mustelid trapping, the National Park and 1080 treatment within the Flora (C).

Stoat trapping in the Flora is a collaborative effort between FOF and DOC. The first stoat traps were installed in 2001, and the trapping area doubled after roroa were re-introduced to cover about 9,000 ha in 2020 (Fig. 1). Trap lines are spaced approximately 1 km apart with trapping stations at 100 m intervals along the lines. At the start of the project, trapping stations had a variety of single-set traps, but these were changed during the project to double-set DOC150 traps. Traps are serviced approximately monthly. The area adjoins the Cobb Valley, in which the community group Friends of Cobb have trapped stoats since 2006. The Flora is on the edge of a much larger area that received aerial applications of sodium fluoroacetate (1080) for control of rats (*Rattus* spp.) three times during this study (Fig. 1). Secondary poisoning of mustelids occurs from such applications of 1080 (Murphy *et al.* 1999; Elliott & Kemp 2016; Robertson *et al.* 2019).

Field monitoring

Post-translocation fieldwork was undertaken by FOF volunteers working with two part-time, contracted ecologists accredited to handle kiwi.

All translocated kiwi were banded and fitted with a GSK diagnostic v2.0 VHF transmitter (Wildtech/Lotec). The transmitter's signal includes pulses of data giving the number of hours the kiwi has been active for each of the previous 14 nights. Kiwi were monitored approximately every 14 days by remote telemetry giving a near-continuous record of their activity pattern. Non-breeding adult roroa were active for 89.4% of civil night, the period when the sun is more than 6° below the horizon (number of nights monitored, n = 38,223; 95% confidence interval (*CI*), 89.2–89.5%). Subadults were active for longer than adults (102% of civil night; n = 1,992; 95% *CI*, 101.3–102.7%). Since both parents share incubation at night, we put transmitters on both male and female roroa to make it easier to recognise a reduction in activity indicative of the start of incubation. Experience showed this was at least four hours/night by both adults for at least a week. Activity occasionally reduced for shorter periods for other reasons, such as heavy snowfall.

Many studies of kiwi breeding success use lightweight chick and juvenile radio transmitters to determine the fate of chicks and juveniles (Robertson & de Monchy 2012; Robertson *et al.* 2016; Tansell *et al.* 2016). Chick transmitters have been fitted to roroa at Arthur's Pass with no apparent effect on their survival (G. Kates *pers. comm.*), but in one case roroa adults abandoned a chick after it was caught and fitted with a transmitter and the chick subsequently died (Harper *et al.* 2011). In addition, one chick died after its transmitter was caught in vegetation (S. Yong *pers. comm.*). To minimise risks to chicks, we chose not to fit chick transmitters but to use a combination of remote radio-tracking of adults and Ltl Acorn 5210A wildlife trail cameras trained on the nest burrow entrance. This limited the information that could be captured since cameras do not record what happens inside the nest or away from the nest entrance. In addition, they are designed for animals the size of deer (Caravaggi *et al.* 2017), and slow trigger times and difficulties capturing small, fast-moving animals, such as stoats (Little *et al.* 2017) and kiwi chicks (this study) can be problematic.

Best practice for camera monitoring of kiwi nests was being developed during the project (Robertson & Colbourne 2017) so we regularly reviewed our methods with other roroa practitioners. Roroa are prone to abandon nests if disturbed especially in the first weeks of incubation (McLennan & McCann 1991), so we delayed deploying cameras until after 12 days (median, 19 ± 2.0 d) into incubation. The nest burrow was found by radio-tracking the incubating male during the day. Cameras were not deployed if the nest entrance was obscured by dense vegetation. The cameras trigger when passive infrared (PIR) light sensors detect motion. They were set to record 30 s video clips with date stamp following a minimum 1 second activation delay, but we found the delay from trigger to start of video was often longer. We aimed to have two cameras covering each nest burrow entrance. Cameras were fixed to trees about 4 m from the nest entrance, preferably with a clear line of sight. A tripod was used when there was no suitable tree, but only if it could be located away from probable roroa routes to and from the nest burrow. One to two weeks after installation, cameras were checked to see if they were recording events at the nest burrow entrance. If there were few roroa video clips, we looked for alternative nest burrow entrances. The cameras' eight AA batteries and 16 Gb SD card were changed every six weeks. Only the contractors approached nest burrows and great care was taken to minimise noise. The GSK diagnostic v2.0 VHF transmitter signal includes a continuously updated record of the activity of the kiwi over the previous ten minutes, the 'twitch factor'. We checked this signal after every visit to a nest to see if the activity of incubating kiwi rose after our visits.

Approximately fortnightly, we determined the location of all kiwi by remote telemetry (Toy & Toy 2020) and used this information, together with the record of activity hours, to determine if nests had been abandoned. We inspected nests as soon as possible after abandonment to try to determine the reason.

Each year, after the breeding season, all kiwi with a transmitter were caught to change the transmitter. We searched for juveniles or subadults

roosting with the adult at this time. We did not band juveniles or subadults in accordance with best practice (Robertson & Colbourne 2017), nor attach transmitters to avoid having to catch the young kiwi repeatedly to check the transmitter's attachment.

Routine telemetry was done by day to estimate the position of roroa roosts. In addition, we monitored the nocturnal movements of breeding kiwi on five occasions: two pairs of incubating kiwi, one at 40 d pre-hatch, one at 8 d pre-hatch; and a third pair, at three, 25, and 59 days post-hatch. Night monitoring involved recording bearings of kiwi taken from three to four fixed locations every 20 minutes throughout the night. Bearings taken at night are approximate because the signal volume fluctuates as the kiwi moves. The accuracy of night-time triangulations could not be quantified (Toy & Toy 2020), but they provided an indication of the proportion of the night the adult roroa spent in the vicinity of its nest.

Interpretation of video monitoring

All video clips were inspected using Windows Media Player. Metal bands glint on nocturnal video, enabling male (band on right leg) to be distinguished from female (band on left leg). The timing of any kiwi activity, the identity of the kiwi, and its behaviour at the nest entrance were recorded. The presence of a chick was sometimes determined by chirruping sounds on the video when a parent returned to the nest burrow, even when the chick was not seen on video. The timing and identity of any other species visiting the nest were also recorded, together with a description of any interaction between the kiwi and the visitors.

Chicks hatch after about 70 days of incubation (Heather & Robertson 2015). A marked increase in adult activity before the expected hatch date, combined with the male roosting away from the nest burrow, indicated incubation failure. Adult roroa do not leave the nest unattended for several nights around chick hatch (Forder 2014). We identified that a chick had hatched when one or both parents had activity of less than three hours for several nights. In addition, after hatch most females started roosting in the nest burrow during the day.

Nest monitoring using cameras did not capture all activity and some interpretation of the results was required to determine the outcome of a breeding attempt. The cameras never directly recorded a chick death. A high probability of chick death was concluded *post hoc* by: video footage of a predator entering the nest prior to or at the time of abandonment, followed by atypical adult behaviour at the nest; adults abandoning the nest when the chick was particularly vulnerable, (i.e. less than 30 days old); the chick outside the nest burrow during daylight immediately prior to nest abandonment; the parents abruptly roosting far from the nest. Atypical behaviour of parent kiwi included prolonged sniffing around the nest entrance, walking around the entrance to the nest for an extended period, and multiple entries and departures from the nest burrow over a period of minutes.

Determining cause of chick death also required interpretation. We attributed death to stoat predation when a stoat entered the nest prior to or at the time of abandonment followed by atypical adult behaviour at the nest. Video footage of a stoat around but not in the nest prior to abandonment, or in the nest within two weeks after abandonment, was taken to indicate probable stoat predation.

Kiwi weighing 1.2 kg are generally able to defend themselves from stoat predation ('safe weight'), but young kiwi become much less vulnerable to predation by stoats when they reach 800–1,000 g at about six months old (Robertson & Colbourne 2017). Young roroa sometimes roost with their parents for several years. We were able to determine that a chick had reached safe weight if it was found as a subadult (more than six months old), when we changed its parents' transmitters. In addition, small kiwi, with skinny legs, without a metal band, and usually with bouncy movements, were sometimes seen on video during incubation or when the chick was very small. We assumed these were subadults hatched the previous year that had reached a safe weight, having survived more than a year.

"Chick fate unknown" was concluded for those nesting attempts for which there was no clear evidence that a chick had survived to safe weight or that it had died.

Kaplan-Meier analysis (Robertson & Westbrooke 2005) was used to calculate the survival rate of adults and chicks. This analysis assumes that when monitoring is truncated due to a dropped transmitter or disappearance of the kiwi, this should not be associated with a higher chance of death. The number of days after hatch that the adults abandoned the nest was used as the period for chick survival or death, rather than the date the chick was last seen.

RESULTS

Use of cameras

We installed cameras at 38 of 55 nest burrows over eight seasons. We analysed 18,491 video clips, but the cameras missed some activity because of the time lag between trigger and start of recording, poor camera positioning, or the nest entrance being obscured. No nests were abandoned as a result of installing and servicing cameras. On no occasion

was the 'twitch factor' of an incubating male's transmitter raised after we visited a nest, providing assurance that there was no obvious disturbance from these visits. On the night following camera installation, one female atypically wandered around the nest for 30 mins before entering. In another case, the male was not active at all and the female had abnormally high activity for two nights. All these kiwi subsequently incubated normally. Six other female kiwi briefly investigated a newly installed camera before entering the nest.

Stoats, weasels (*Mustela nivalis*), common brushtail possums (*Trichosurus vulpecula*), and western wēkā (*Gallirallus australis australis*) were the only potential predators seen to enter a nest burrow. Cats and ferrets (*Mustela furo*) were not recorded, although a feral cat has been seen on trail camera video elsewhere in the Flora. At one nest, kea (*Nestor notabilis*) were seen, but they did not enter the nest burrow. Goats (*Capra hircus*), fallow deer (*Dama dama*), and rodents (*Mus* spp. and *Rattus* spp.) were also seen outside nest burrows.

Breeding success

We monitored 26 paired adult roroa through between one and eight breeding seasons, 22 (85%) of which attempted to breed. Fifty-five breeding attempts were identified (Tables 1 & 2). Chicks hatched from 26 (47%) breeding attempts. Productivity expressed as the number of chicks hatching/adult/year was 0.217.

There was strong evidence that 10 of 26 chicks (38%) died, nine of them within 30 d of hatch. Six (23%) chicks were seen as subadults greater than one year old in the year following their hatch. There was insufficient evidence to determine the fate of the other 10 (38%), which included three chicks whose survival to one year could not be determined because they hatched less than a year before the end of the project (Table 1). Excluding these three chicks, minimum survival to one year was 26% (six of 23). At 105 d, the longest period after hatch a nest burrow was occupied, the Kaplan-Meier chick survival estimate was 52%. Of the six chicks that survived to one year old: four were seen six or fewer times when less than three months old; five were seen on video when about a year old, and the sixth was with its parents at 13 months old when we changed their transmitters. This illustrates how easily chicks may go undetected and suggests that some of the chicks of 'unknown' fate may have survived; actual survival to one year may have been closer to 52% than to the minimum 26%.

The study comprised 148 years of adult kiwi monitoring during which three are known to have died, two of them before they established home ranges (Toy & Toy 2020). The Kaplan-Meier adult

Table 1. Summary of the outcome of 55 known roroa breeding attempts in the Flora between 2010 and 2018. Breeding seasons are July–June annual periods. The project ended in 2018, so there was no opportunity to determine how many of the chicks alive at that time survived to one year (n/d).

		2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	Total
Number of roroa monitored	Single	1	2	1	15	4	1	12	4	40
	Non-breeding pairs	5	4	2	2	1	1	3	1	19
	Breeding pairs	0	0	3	5	9	9	6	10	42
Breeding attempts		0	0	4	5	15	11	6	14	55
Incubation fate	Total failed comprising:	-	-	3	1	10	6	2	7	29
	Infertile/ inviable egg			1	0	2	1	0	1	5
	Eggs depredated/ broken			0	0	1	2	1	3	7
	Died at expected time of hatch			0	0	0	1	1	1	3
	Unknown cause			2	1	7	2	0	2	14
	Chick hatched	-	-	1	4	5	5	4	7	26
Chick fate to 1 year	Known to have survived	-	-	0	1	2	1	2	n/d	6
	Strong evidence died	-	-	1	1	1	3	0	4	10
	Unknown	-	-	0	2	2	1	2	3	10

annual survival rate was 98.4%. As no subadults are known to have died, subadult survival was assumed to be 97.4%, the reported annual survival of subadult South Island brown kiwi (Haast tokoeka, *Apteryx australis australis*) (Robertson & de Monchy 2012). Adult survival of 98.4%, subadult of 97.4%, the minimum chick survival rate of 26% and productivity of 0.217 chicks/adult/year, were used to populate a Leslie matrix giving 3.4% annual population growth. If all the chicks with unknown fate survived, the population growth rate would be 7.0%.

The six chicks known to have reached one year originated from two pairs. One of these was translocated as a pair; the other comprised a translocated, single female paired with a non-translocated, immigrant kiwi. A further 12 adults (seven pairs because there were partner changes) had a chick whose fate we could not determine. Five of the 16 monitored breeding pairs in the Flora comprised partners from different source sites (Table 2).

Chicks are known to have survived to one year old in the four breeding seasons from 2013–2014 to 2016–2017 (Tables 1 & 2). Mustelid numbers, as indicated by trapping station catch rate, varied greatly over this period (Fig. 2). Successful chicks hatched between 21 November and 1 April, the latter from a pairs' third incubation attempt for the breeding season.

Two subadults were found with a kiwi other than their parent when we changed the transmitters on the translocated kiwi, demonstrating pairing of Flora-bred roroa, although we did not monitor for long enough to know if they bred.

Roroa breeding biology

Four pairs from the first translocation established home ranges in 2010, but none of them bred until 2012. By contrast three pairs from later translocations bred in the year they were translocated, and a further four pairs bred the year after translocation. Once pairs started to breed, 73% (eight of 11) of those we monitored for more than one year, did so every year. All three that missed a year did so in the same year, 2016–2017. Two pairs, one monitored for six years and another for four years, never attempted to breed (Table 2).

Nests were located in natural cavities, generally under tree boles or root plates (n = 21), but also in hollow logs (n = 10), rock caves (n = 6), or other natural underground cavities (n = 3).

Incubation of the initial one egg clutch of each season started between 24 July and 22 November (n = 42). Eleven of 23 (48%) breeding attempts that failed before or during chick hatch, were followed by a second attempt starting between 14 October and 23 December and two of them by a third attempt starting between 16 January and 25 February. Repeat incubations started on average 55 d (n = 13; 95% *CI*, 47–62 d) after the previous attempt failed. For breeding attempts with clear start of incubation and chick hatch dates, incubation averaged 76 d (n = 20; 95% *CI*, 75–77 d).

Male roroa incubated the egg during the day. The female took over the incubation on average 1 h 50 mins after sunset (n = 298; 95% *CI*, 1 h 41 mins – 1 h 59 mins); she generally arrived before the male left, but sometimes after he had departed, leaving the egg unattended (Fig. 3A). The median

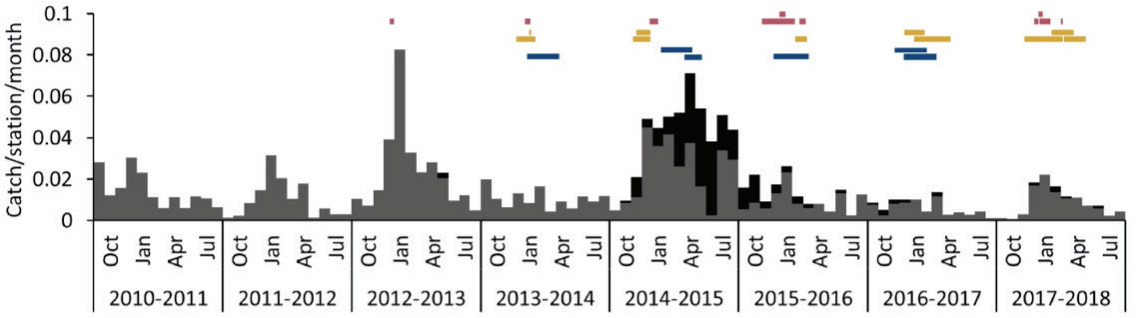

Figure 2. Fate of roroa chicks in the Flora in relation to mustelid trapping rate, showing that chicks survived in most years even though mustelid catch rate varied greatly. Grey and black bars represent stoat and weasel catch/trapping station/month. Each coloured line represents the monitoring period of a single chick: purple, chick died; yellow, chick's fate unknown; blue, chick survived to one year. Transmitters were removed from adult roroa in 2018, so we could not know if chicks in 2017–2018 survived to one year.

Table 2. Breeding success of monitored pairs of adult roroa in the Flora from 2010 to 2018. Origin indicates the site from which translocated kiwi were sourced: CR, Clark River; NC, New Creek; RL, Roaring Lion; SG, South Gouland; Flora, a natural immigrant. * identity unknown (probably Anaweka). Grey cells show the number of failed incubation attempts; purple, the number of chicks with strong evidence of death; yellow, the number of chicks with unknown fate; blue, the number of chicks known to have survived to one year. Blank cells indicate the pair was not known to exist, or was not monitored in that particular season.

Male	Female	Origin	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018
Anatori	Anaweka	CR/CR	0							
Anatori	*	CR/*			1					
Anatori	Korowhiti	CR/NC					3	1	1	
Anatori	Mangarakau	CR/SG							1	1
Hoire	Poai	RL/RL				1	2	1	1	1
Mr Cobb	Iwa	Flora/NC					1	1	1	1
Parapara	Totaranui	CR/CR	0	0	0	0	0	0		
Pikopiko	Pakawau	CR/CR	0	0	2	1	1	1	1	1
Rakopi	Aorere	CR/CR	0	0	0	0				
Tahi	Torongangara	NC/RL						1	0	1
Tai Tapu	Rata	SG/SG								2
Te Manu-huna	Ngutu-roa	RL/RL				1	1	1	0	1
Toru	Rua	NC/NC					1			
Waiharakeke	Rameka	CR/CR	0	0	1	1	1	1	1	1
Whakangangahu	Torongangara	RL/RL				1	1			
Whakangangahu	Te Kau	RL/NC						1	1	1
Whitu	Whakahihi	NC/NC					2	1	0	1
Total breeding attempts			**0**	**0**	**4**	**5**	**15**	**11**	**6**	**14**

evening handover period was two minutes overlap and was not significantly different for incubations that failed and those from which a chick hatched (Mann-Whitney, n_1 = 232, n_2 = 62, U = 6,834, p = 0.429). During 65% of nights, the female left the nest prior to the male returning (Fig. 3B). If the male had not returned, she sometimes climbed onto a raised location and called, but the male did not always return immediately (Fig. 4A). Absence was more common in the morning than in the evening; the median morning handover was 26 minutes absence if the incubation failed and 28.5 minutes if the chick hatched, a non-significant difference (Mann-Whitney, n_1 = 184, n_2 = 61, U = 5,006, p = 0.206). On average, the male was away from the nest for 5 h 25 mins (n = 138; 95% *CI*, 5 h 12 mins – 5 h 37 mins), equivalent to 60 ± 2.1% of civil night. On average, the female was in the nest burrow for 4 h 39 mins (n = 263; 95% *CI*, 4 h 30 mins – 4 h 49 mins). Around dawn, 60% of females returned to the nest, not every day but some more regularly than others, for an average of 15 mins (n = 16; 95% *CI*, 9–21 mins). One female regularly visited the nest at various times during the day throughout incubation.

Overlapping handovers usually occurred inside the nest burrow. However, sometimes the incubating kiwi would emerge and the two kiwi would interact (Fig. 4B), occasionally allopreening.

Throughout the breeding period, the parents 'gardened' outside the nest. This comprised tossing fallen leaves, pieces of lichen and twigs more-or-less in the direction of the nest entrance. It never resulted in the entrance becoming blocked or obscured, and 'gardening' sometimes took place a few metres from the nest entrance. All monitored roroa performed this activity, typically on leaving the nest but also, especially males, on return to the nest. The frequency of this behaviour varied between individuals but some did it most nights, and for up to seven minutes.

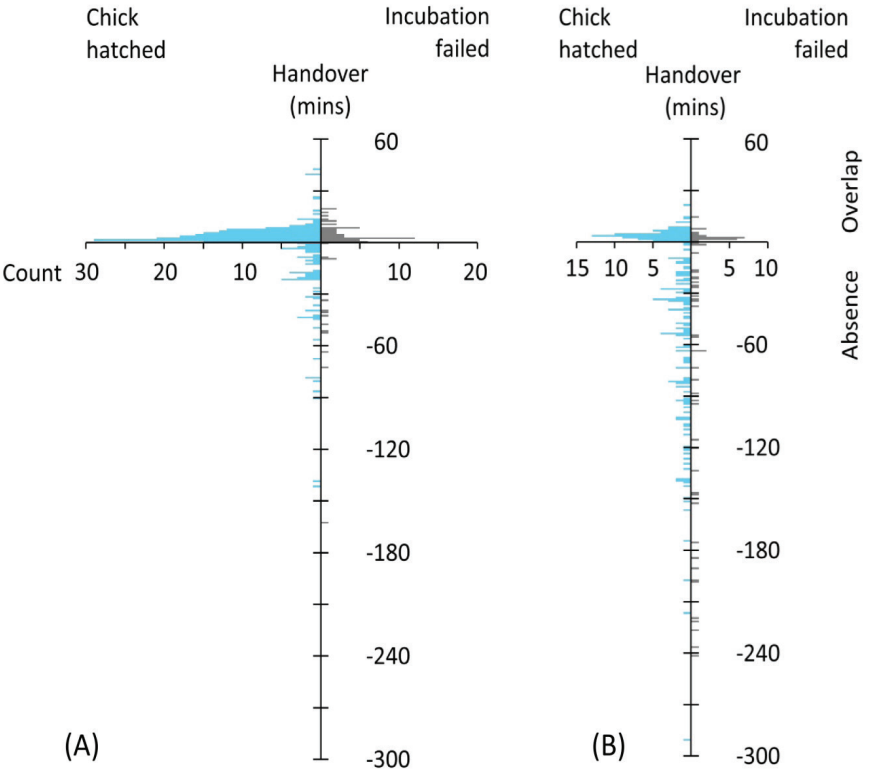

Figure 3. Male roroa incubate during the day, both female and male incubate at night. Mirrored histograms showing: nests in which chicks hatched in blue; nests in which incubation failed in grey. The count is the number of handovers of each duration. Evening handovers (A) are the time between male departure and female arrival, and morning handovers (B) are the time between male return and female departure. When nests are unattended handover periods are negative; when male and female are both in the nest, handover periods are positive (overlaps).

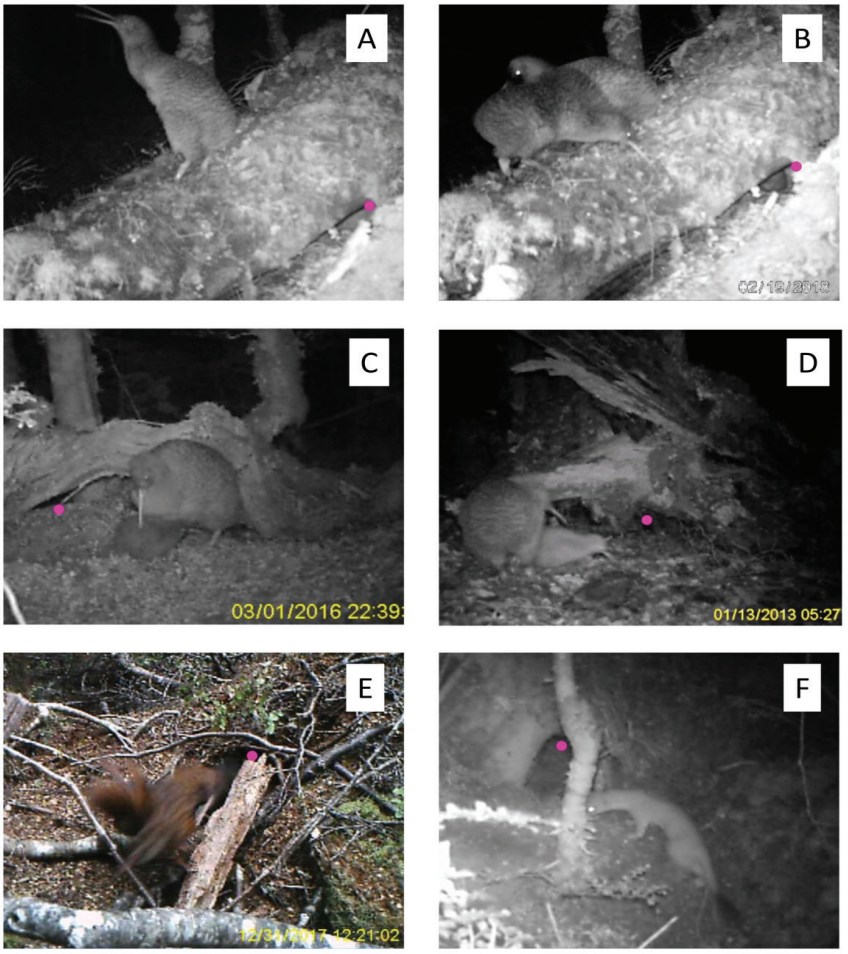

Figure 4. Images from video monitoring of roroa nest entrances in the Flora. Nest entrances are shown by pink spots. (A) female roroa calling outside the nest immediately after her incubation spell. She departed immediately afterwards even though the male had not returned; (B) adult interaction outside the nest. The chick, estimated to be 14 day old, is visible in the nest entrance; (C) male roroa 'brooding' a young chick outside the nest the first night it was seen on video; (D) male roroa ushers a chick, estimated to be 29 day old, into the nest shortly before dawn; (E) male roroa, whose beak is visible to the left and below the pink spot, chases a wēkā from the nest entrance, during incubation; (F) a stoat continuing to visit a nest entrance two days after the chick was apparently depredated.

The chick was first seen outside those nest burrows with good camera coverage, an average of nine days after hatching ($n = 18$; 95% *CI*, 8–10 days).

At first emergence, the chick looked unsteady and remained close to the nest entrance and was usually accompanied by at least one parent. Active parental care continued outside the burrow with some adult kiwi appearing to try to brood newly-emerged chicks outside the nest (Fig. 4C), although we did not see parents actively defending the chick. By 30 days after hatch, chicks looked stronger and moved rapidly, but were still sometimes ushered into the nest by a parent kiwi (Fig. 4D). Both parents' activity had returned to all the hours of darkness within 15 days of chick emergence.

All-night radio-tracking showed that three and 25 nights after hatch the male of one pair remained within 200 m of its nest burrow. A week before hatch a different male remained within 300 m of its nest burrow. Non-breeding kiwi roamed more widely (Toy & Toy 2020).

The chick roosted in the natal burrow for up to three months after hatch, normally with both adults, but sometimes only one. However, on one

occasion both parent kiwi were identified roosting 67 m from the nest burrow, and a 33 d old live chick was found when the nest was inspected.

Five subadult roroa were seen visiting nest burrows both during incubation and after chick hatch. One subadult visited frequently during the night, interacting with the adult female. It also spent some days in the nest burrow with the incubating male. The other subadults were seen only once or twice and weren't seen to enter the nest burrow.

Incubation failures

Cameras were not essential to determine the outcome of a breeding attempt, but were the primary means of determining why 15 of 29 (52%) incubation attempts failed: infertile/inviable eggs (5); predation/broken eggs (7); and death at expected time of hatch (3) (Table 1). The five infertile/inviable eggs were abandoned from 17 to 70 days into incubation. Of two abandoned eggs that could be recovered, one contained a late stage embryo, the other was either unfertilized or had an early-stage embryonic death. All five pairs that produced an infertile/inviable egg later bred successfully, two of them from a second clutch in the same year they produced an infertile/inviable egg. Three nests that were abandoned close to the expected time of hatch may have had a very late embryo death or the chick may have died during hatching. At one of these, a wēkā was seen running off with a late-stage embryo.

Stoats were seen during incubation outside 11 nest burrows and weasels outside two. Chicks hatched at ten of these nests, but one nest was abandoned shortly after the stoat was seen in the entrance and it is assumed the egg was broken during the stoat's visit. Possums were seen around five nest burrows; only one was seen to enter, but it emerged rapidly and the chick later hatched.

Wēkā were seen at 91% of monitored nest burrows, mostly during the day, and harassed the incubating kiwi at 60%. Harassment typically involved: the wēkā approached the burrow slowly, often with feathers erect and head lowered, peered in and sometimes disappeared inside; the wēkā emerged rapidly, sometimes pursued by the adult kiwi, who would circle around and rapidly return to the nest (Fig. 4E); the wēkā returned within minutes and the sequence was repeated. Harassment continued for prolonged periods; for example, in one five-hour period we observed four bouts of harassment during which the kiwi chased after the wēkā eight times. The most intense period of harassment continued for eight minutes, during which the adult kiwi exited its burrow 19 times.

We attributed 21% (six of 29) incubation failures to wēkā: in three, wēkā were seen eating part of the egg; in two, the kiwi abandoned the nest soon after a prolonged period of harassment and chasing; in one, a wēkā entered an unattended nest which the kiwi abandoned later the same night. We could not discern if wēkā broke eggs or if they were accidentally broken by a harassed adult kiwi. Wēkā visits occurred at all stages of incubation. Five of the wēkā-induced incubation failures occurred when the nest was occupied, four during the day and one at dusk; the sixth occurred during the night when the nest was unoccupied for a period of 65 minutes.

Chick deaths

There was strong evidence that ten chicks died, five of them for unknown reasons (Table 1). Three deaths were attributed to stoat predation, and two others were probably due to stoat predation (Fig. 4F), at 17 to 94 days old. However, three chicks survived to one year old even though stoats or weasels had visited the nest burrow between one week and three months after hatch. Ten nests, at which the fate of the chick was unknown, were abandoned when the chick was between 33 and 105 days old. There was no evidence of chick predation by wēkā and chicks survived to one year despite wēkā visits to, and eviction from, the nest burrow after chick hatch.

DISCUSSION

Friends of Flora's monitoring has demonstrated that the project is on track to meet longer term translocation goals; roroa are successfully breeding and young birds appear to be forming new pairs within the Flora. We calculated hatch success and an estimated range for chick survival. However, methodological limitations meant that cause of hatching failure, chick fate and cause of chick death could not always be determined.

Breeding success

Annual population growth of roroa in the Flora was estimated as 3.4%. This may be an overestimate if kiwi whose monitoring was truncated, dispersed into areas with less predator control or where dog predation was more likely. Conversely, annual growth rates may have been higher if chicks of unknown fate survived. Notwithstanding this uncertainty, it appears that population growth rate exceeds the current Kiwi Recovery Plan goal of 2% per annum (Germano *et al.* 2018).

Population growth parameters have not previously been published for roroa. However, other South Island kiwi species, South Island brown kiwi (Fiordland tokoeka, *A. australis australis* and Haast tokoeka, *A.a.* 'Haast') and Okarito brown

Table 3. Comparison of breeding success of the roroa translocated to the Flora with that of other South Island (New Zealand) kiwi in areas with predator control. Numbers in italics are estimates due to limited data. Monitoring chick survival using cameras (this study) estimated a lower bound on survival to one year. The upper bound is the Kaplan-Meier estimate of chick survival at 105 d. Studies are: A) Flora, NW Nelson, 9,000 ha stoat trapping (1 box/8 ha), periodic 1080 for rats (this study); B) Murchison Mountains, 15,000 ha stoat trapping (1 box/21 ha) (Tansell *et al.* 2016); C) Haast, 11,400 ha stoat trapping (1 box/8 ha), trapping preceded by 1080 for possums (Robertson & de Monchy 2012); D) Okarito, 12,000 ha stoat trapping (1 trap/4 ha), various sporadic toxins for possums (Robertson & de Monchy 2012). Tansell *et al.* (2016) also reported on productivity in an unmanaged area which is not included here.

Species		Roroa	Fiordland tokoeka	Haast tokoeka	Rowi
No. of monitored pair years		61	67	127	191
No. of eggs		55	56	88	184
Hatching success (%)		47	46	62	48
Chicks/pair/year		0.43	0.39	0.44	0.46
Survival	0–1 y	0.26–0.52	0.326	0.278	0.145
	1–2 y	*0.974*	0.917	0.974	*0.920*
	2–3 y	*0.974*	0.900	0.974	*0.940*
	3–4 y	*0.974*	1.000	0.974	*0.960*
	Adult	0.984	0.962	0.978	0.979
Annual population growth, r (%)		3.4	1.2	2.9	0.6
Study		A	B	C	D

kiwi (rowi, *A. rowi*) also have single-egg clutches, males and females share incubation and population growth studies have been carried out in areas with mustelid control. Numbers of chicks hatching/pair/year are similar for roroa and the other species (Table 3). The use of chick and juvenile VHF tags on tokoeka and rowi allowed for specific survival estimates to one year, but in the Flora, with the inherent limitations of our camera trap data, a specific roroa estimate could only be made to 105 d. Survival to one year based on re-finding subadult roroa in the Flora is similar to Fiordland tokoeka and Haast tokoeka, but lower for rowi. Multi-year use of the natal burrow, during which scent trails develop that stoats follow to the nest, may have contributed to the lower survival of young rowi (Robertson & de Monchy 2012). Adult survival rates are slightly lower for tokoeka and rowi than we estimated for roroa. Overall, the higher Flora survival estimates lead to higher roroa population growth estimates particularly than rowi and Fiordland tokoeka.

Causes of breeding failure

It is important to understand causes of kiwi breeding failure to enable management to be adjusted (Robertson & De Monchy 2012). The egg was infertile/inviable in 9% of incubations. High microbial loads inside the nest (McLennan *et al.* 1996; Robertson 2004) may be a cause of inviable eggs. Nest sanitation behaviour, involving exchange of nest material for leaves placed in the nest entrance may help reduce microbe loads (Forder 2014). Our camera footage showed 'gardening' behaviour both before and after incubation failure, but we never observed exchange of nest material, and 'gardened' leaves and twigs rarely reached the nest burrow entrance. In contrast, little spotted kiwi and North Island brown kiwi (*A. mantelli*) have been reported to block the nest entrance (Colbourne 2002). Nest camouflage might reduce predation of little spotted kiwi from wēkā (Jolly 1989) or maintain high humidity in the nest to reduce water loss from the egg (Colbourne 2002).

Wēkā are a flightless rail endemic to New Zealand. Their numbers fluctuate widely (Marchant & Higgins 1993; Heather & Robertson 2015) and increased in the Flora during this study (RT & ST *pers. obs.*). They are highly inquisitive, and could have followed us to monitored nest burrows, but it seems likely that during a 76-day incubation period, they would have found at least some nests

independently. On Kapiti Island, wēkā, which were present at high density, depredated little spotted kiwi eggs, and probably a newly hatched chick (Jolly 1989). In the Flora, wēkā frequently harassed the incubating kiwi but caused only 11% of breeding attempts to fail. Roroa defence of their egg against wēkā appears relatively effective.

Natural productivity, the number of chicks hatching naturally/pair/year, reflects all reasons for incubation failure and is similar for roroa in the Flora to that of other South Island kiwi species (Table 3). We therefore conclude that *ex-situ* incubation of eggs is not necessary.

Mustelids were the only cause of chick deaths that we identified. We would expect roroa nests to be easily detectable by mustelids, which have a keen sense of smell (King & Powell 2006), not least because roroa, particularly males, often defecated immediately prior to entering the nest burrow and nest burrows were occupied for up to six months. Adult kiwi attended their young chick closely, which may provide protection from predators or may have other functions; for example, ongoing brooding of a chick, observed up to 26 days after hatch, may conserve energy in a cold environment (Forder 2014).

Chicks are known to have survived to one year old in each year from 2013–2014 to 2016–2017 (Tables 1 & 2). Over this period mustelid numbers, as indicated by the number trapped, varied greatly (Fig. 2). Since the number of chicks reaching safe weight exceeds the number of adult deaths, we conclude the current predator control regime in the Flora is adequate. The periodic use of 1080 to supplement trapping reduces the risk of selecting for stoats that do not enter traps (Robertson *et al.* 2016) and reduces the size of stoat irruptions in beech mast years (Elliott & Kemp 2016). The fate of ten chicks was unknown; some of these may have been depredated by mustelids, but other factors may also have had an impact. A range of factors including food supply, climate, disease and the impacts of browsing mammals on forest structure may lead to population declines of forest birds (Innes *et al.* 2010).

Long-term translocation success

The successful post-translocation breeding in the Flora needs to be viewed in a wider temporal context. We monitored for up to eight years after translocation, a relatively short period compared to an estimated roroa life expectancy of 57 years (DOC *unpubl. data*). Four roroa were known to be contributing founders and another 12 had a chick of unknown fate. The reasons that two pairs were repeatedly successful in getting chicks to one year, while others did not, were not evident. We did not observe differences in behaviour around the nest; home ranges of the successful pairs were adjacent to others that were unsuccessful; and differences in home range size and habitat composition were not evident. Tansell *et al.* (2016) suggest that the low number of breeding Fiordland tokoeka in their study population may reflect an aging population with few young birds and reproductive senescence in the older birds. In the Flora, the females of the two persistently non-breeding pairs also appeared old, each with worn hocks and an opaque eye. Excepting these two pairs, there is nothing to suggest that over a longer timeframe other translocated roroa won't become contributing founders.

Recruitment of Flora-bred roroa to the breeding population was not demonstrated during this study. Intensive monitoring of Flora-bred kiwi would have been required to determine whether they also bred successfully. This would have to continue for many years, given that the usual age of first breeding in kiwi is about four years old (Robertson & de Monchy 2012).

Reintroductions also need to be viewed in the context of wider landscape predator control and safe opportunities for dispersal and gene flow (Richardson *et al.* 2015). The Flora forms part of Kahurangi National Park that has received periodic applications of 1080 over up to 270,000 ha (Elliott & Kemp 2016), and is contiguous with stoat-trapped roroa habitat in the Cobb Valley. Roroa call rates in the Cobb Valley are low (Toy *et al. unpubl. data*), suggesting the potential for immigration may be limited. However, one translocated female paired with a non-translocated immigrant and had chicks reach a year old, demonstrating that genetic supplementation of the translocated population has already occurred.

Future steps

Translocations can be designed to minimise loss of genetic diversity by sourcing founders from large, wild, genetically diverse populations with no evidence of inbreeding depression (Weeks *et al.* 2015); using multiple source sites; translocating more individuals (Tracy *et al.* 2011; Jamieson & Lacy 2012) and, increasing the area of trapping. We adopted all these measures and do not anticipate that the Flora roroa population will show long-term genetic problems from having an inadequate number of founders. Modelling of a closed population of North Island brown kiwi, indicated that 19 additional immigrants would need to be added each generation to maintain 90% of rare alleles, which is desirable for long-term persistence of the population under changing conditions (Weiser *et al.* 2013). Carrying capacity in this modelling was set at 108 kiwi and was one of the most influential parameters. The Flora is not a closed population, suitable habitat exists to the north, west

and south, and immigration has been observed. Nevertheless, the reproductive skew observed in eight years of monitoring indicates a longer-term strategy to determine genetic health is desirable. Continuing to monitor the breeding of kiwi fitted with transmitters, was rejected as too disruptive to the kiwi. Use of periodic genetic assessment can be used to identify potential long-term problems such as lower than expected genetic diversity that could result from unequal contribution of founders in a translocated population (Dresser *et al.* 2017). If such genetic assessment detects a problem, active genetic management can be considered (Groombridge *et al.* 2012), for example further translocations (Tracy *et al*. 2011; Weiser *et al*. 2013) or selectively removing offspring of over-represented lineages (Jamieson 2011). Since removing transmitters, the distribution and call rates of roroa in the Flora are being monitored using acoustic recorders. This provides information on long-term changes in call rates, which may reflect changes in population size and also detect new home ranges established since removing transmitters from the translocated kiwi. The data from acoustic recorders could be used to target a survey to catch as many birds as possible or to use certified kiwi dogs to find kiwi or their roost sites for collection of feather samples or scats. Genetic comparison can be made with DNA in pin feathers retained from the translocated roroa; this will show whether more translocated kiwi have become contributing founders.

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